C2.3 Heaving and Pitching Airfoil

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1 Code description

SUNWinT [1] is a high-order Discontinuous Galerkin CFD solver which solves the Euler, Navier-Stokes and Reynolds-Averaged Navier-Stokes equations with the Spalart-Allmaras model. We employ modal basis functions up to a polynomial degree $p = 5$ which are implemented for triangle, quadrilateral, tetrahedral and hexahedral elements. For temporal discretisation explicit Runge-Kutta schemes upto 4th order, an implicit BDF2 method and an implicit Euler backward method can be used. The inviscid flux over element faces is calculated with a HLL Riemann solver, while for viscous fluxes we use the BR2 scheme. The code is parallelised via MPI and meshes for the parallel runs are split with metis. Linear meshes are created with Gridgen and a higher-order mesh can be created based on normals [2] or by aggregation.

2 Case description

The case utilises the ALE capabilities of the code to handle the movement of the airfoil. Mesh deformation is achieved with Radial Basis Functions. An implicit BDF2 method is used for time marching and spatial discretisation ranges from $P3$ to $P5$. The time step was set $\Delta t = 2E - 3$. At the outer boundary freestream conditions were applied and a no-slip boundary conditions was applied at the airfoil.

3 Meshes

A mesh consisting of 4408 cells curved by cubic polynomials was created. It is a normal C-Grid with the farfield located 100 chords from the airfoil (compare figure 1).

4 Results

The drag coefficient for the static simulation are shown in table 1. The history of the vertical force and the torque are presented in figure 2 for Re=1000 and in figure 3 for Re=5000. In figures 4 and 5 the distribution of the pressure coefficient at two different times can be seen. The values of the vertical impulse and the the work which the fluid exerts are presented in table 2 for Re=1000 and in table 3 for Re=5000.

Order	$P3$	$P4$	$P5$
c_d, Re=1000	0.120236	0.120236	0.120236
c_d, Re=5000	0.0526198	0.0526197	0.0526197

Table 1: Drag Coefficient for the static case.

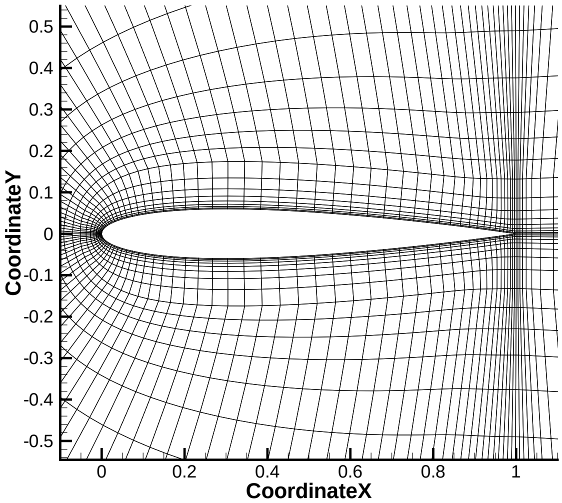
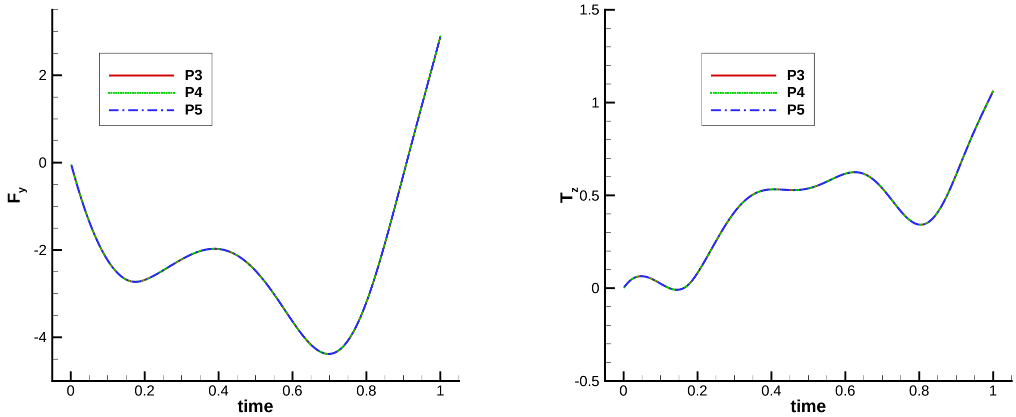


Figure 1: Detail of the computational mesh.



(a) F_y

(b) T_z

Figure 2: History of vertical force F_y and torque T_z for Re=1000.

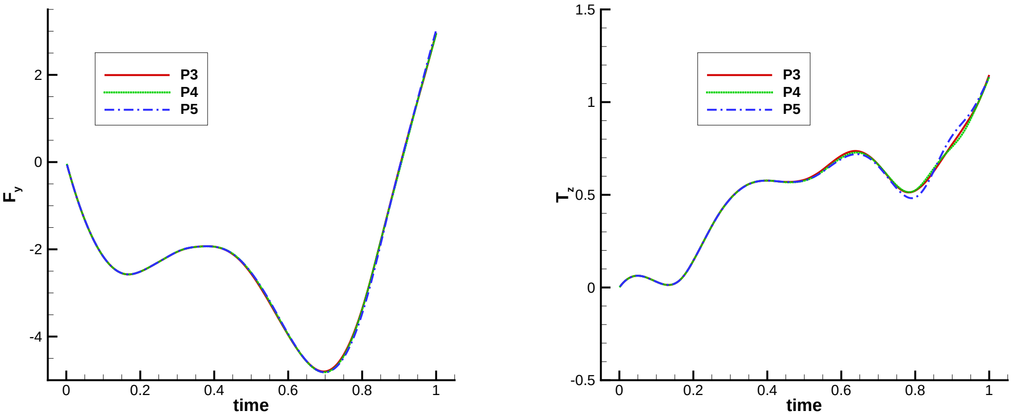
4.1 Computational costs

The simulations were run on the Cray Hermit cluster at the High Performance Computing Center in Stuttgart, Germany. The P3 and the P4 simulation used 128 processors while the P5 simulation used 512 processors. On the cluster TauBench took 9.1098 s on average. The work units and the degrees of freedom per equation for different polynomial orders are presented in table 4.

References

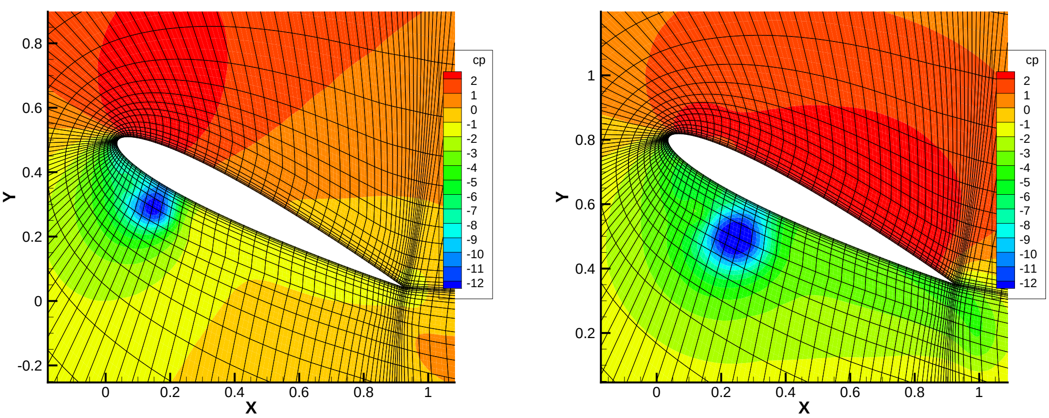
[1] B. Landmann, M. Keßler, S. Wagner, and E. Krämer. A parallel, high-order Discontinuous Galerkin code for laminar and turbulent flows. *Computers & Fluids*, 37(4):427 – 438, 2008.

[2] C. Lübon, M. Kessler, S. Wagner, and E. Krämer. High-order boundary discretization for Discontinuous Galerkin codes. In *24th AIAA Applied Aerodynamics Conference, San Fransisco, AIAA Paper 2006.2822*, 2006.



(a) F_y (b) T_z

Figure 3: History of vertical force F_y and torque T_z for Re=5000.



(a) $t = 0.4$ (b) $t = 0.6$

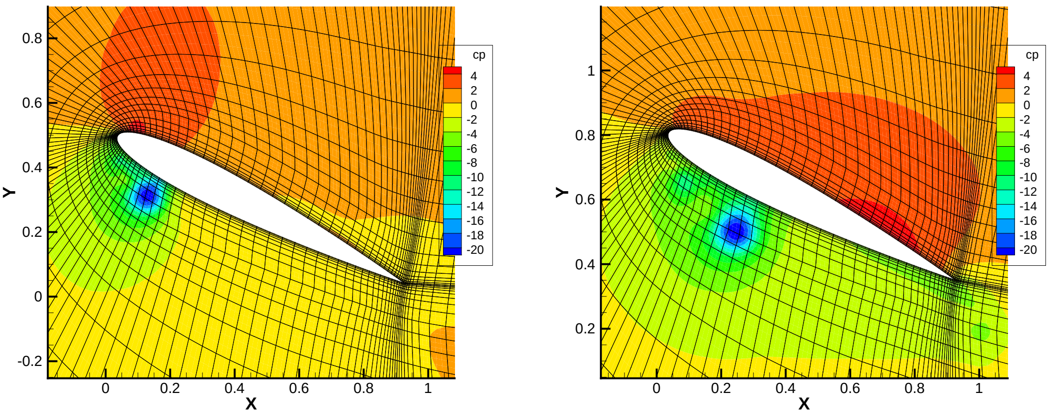
Figure 4: Distribution of the pressure coefficient at $t = 0.4$ and $t = 0.6$ with deformed mesh for Re=1000.

Order	$P3$	$P4$	$P5$
I	-2.21656	-2.21617	-2.21607
W	-2.81730	-2.81686	-2.81672

Table 2: Vertical impulse I and work W for Re=1000.

Order	$P3$	$P4$	$P5$
I	-2.25718	-2.25980	-2.26107
W	-2.89367	-2.89239	-2.88974

Table 3: Vertical impulse I and work W for Re=5000.



(a) $t = 0.4$ (b) $t = 0.6$

Figure 5: Distribution of the pressure coefficient at $t = 0.4$ and $t = 0.6$ with deformed mesh for Re=5000.

Order	$P3$	$P4$	$P5$
nDOFs	44080	66120	92568
Work units	1.3E4	4.3E4	2.3E5

Table 4: Work units for different orders.